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NEUTRON AND PROTON BINDING ENERGIES IN THE REGION OF LEAD

By Katharine Way*

The maxima in α particle decay energies for mass numbers 210-215 recently emphasized by Perlman, Ghiorso, and Seaborg[1] can be looked at in terms of neutron and proton binding energies and, when thus interpreted, reveal rather sharp discontinuities in these bindings at proton number 82 and neutron number 126. The numbers 82 and 126 are two of the "magic" numbers connected with marked nuclear stability on which attention has been focused by M. G. Mayer.[2] If one considers these "magic" numbers as numbers for which neutron or proton "shells" are closed one would expect unusually high binding energies for the 82nd, 81st, etc., proton and for the 126th, 125th, etc., neutron and unusually small bindings for protons with number slightly greater than 82 and neutrons with number slightly greater than 126. As the new shells fill up, the binding energies should gradually return to "normal."

The binding energy of four neutrons to certain heavy nuclei can be found with a good deal of accuracy from known α and β decay energies. Thus the binding energy of four neutrons to U^{234} is equal to $\{$mass (U^{234}) + mass (4 n's) - mass $(U^{238})\}$ or $\{$mass (4 n's) - mass (He^4) - $E\alpha\,(U^{238})$ - $E\beta\,(UX_1)$ - $E\beta\,(UX_2)$ - $E_{recoil}\}$ which equals $\{$29.64 - 4.18 - 0.20[3] - 2.32[4] - .07$\}$ or 22.9 mev. The binding energy of four neutrons to Pb^{208} turns out by a similar calculation to be only 17.6 mev using $E\beta$ (ThB) = 0.88 mev, $E\beta$ (ThC) = 2.20 mev, and $E\alpha$ (ThC') = 8.78 mev. The Bohr-Wheeler[5] liquid drop model with the semi-empirical constants given by them gives 22.8 mev for the binding of 4 neutrons to U^{234} as against 22.9 mev found above. However, for the Pb^{208} value the Bohr-Wheeler model gives again 22.8 mev in marked disagreement with the 17.6 mev found from decay energies.

Assuming that the individual Bohr-Wheeler values for the binding of a neutron to U^{234}, U^{235}, U^{236}, and U^{237} are correct one can calculate binding energies in the region of Pb from known α and β decay energies. For instance

$$B_n(A - 4, Z - 2) = B_n(A, Z) + E\alpha_1 - E\alpha_2$$

when $B_n(A,Z)$ is the binding energy of a neutron to a nucleus with mass A and charge Z and where $E\alpha_1$ and $E\alpha_2$ are the disintegration energies associated with the emission of α particles from the nuclei (A, Z) and

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(A + 1, Z). A similar relation holds for β decay, but here the uncertainties of the results are greater than in the α cases since in many cases decay schemes have not been worked out. Some checks were possible from stability considerations and cycle calculations. In some cases it is necessary to depend on cycle calculations entirely. By such a calculation is meant the value found by requiring disintegration energies leading from the same initial to the same final nucleus to be equal.

Table 1 shows the results. Here the value 7.1 in the first row is the binding energy in mev of the 126th neutron to a nucleus containing 81 protons and 125 neutrons, while the value 7.8 in the second row gives the binding energy of the 82nd proton to the same nucleus. The values found support the shell picture since unusually high binding energies are observed just before and unusually small ones just after the completion of the "shells" at neutron number 126 and proton number 82. The nucleus Pb^{208} containing both 82 protons and 126 neutrons is seen to act like a core, additional neutrons and protons being bound to it by approximately equal amounts.

Results rather similar to those of Table 1 were found by Berthelot[6] in 1942 from consideration of disintegration energies of Pb, Bi, and Po isotopes only.

Table 1. Neutron and proton binding energies.

N																
Z	124		125		126		127		128		129		130		131	
Tl 81				7.1		3.5		4.7		4.0 (?)						
			7.8		7.7		7.7		8.5 (?)							
Pb 82	6.9			7.0		3.5		5.5		4.0		4.6				
					3.5		4.9		4.6		4.8					
Bi 83						4.9		5.3		4.1		4.9		4.3		
					5.3		5.2		5.6		5.4		6.7		6.7	
Po 84						4.8		5.7		4.0		6.2		4.3		5.3
At 85														4.9		5.5

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